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OVERVIEW OF THE ACT PROGRAM

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INTRODUCTION

NASA'S Advanced Composites Program (ACT) was initiated in 1988. A National Research Announcement was issued to solicit innovative ideas that could significantly contribute to development and demonstration of an integrated technology data base and confidence level that permits cost-effective use of composite primary structures in transport aircraft. Fifteen(15) contracts were awarded by the Spring of 1989 and the participants include commercial and military airframe manufacturers, materials developers and suppliers, universities and government laboratories. The program approach is to develop materials, structural mechanics methodology, design concepts and fabrication procedures that offer the potential to make composite structures cost-effective compared to aluminum structure. Goals for the ACT program included 30-50 percent weight reduction, 20-25 percent acquisition cost reduction, and provided the scientific basis for predicting materials and structures performance.

This paper provides an overview of the ACT program status, plans and selected technical accomplishments. Sixteen(16) additional papers, which provide more detailed information on the research and development accomplishments, are contained in this publication.

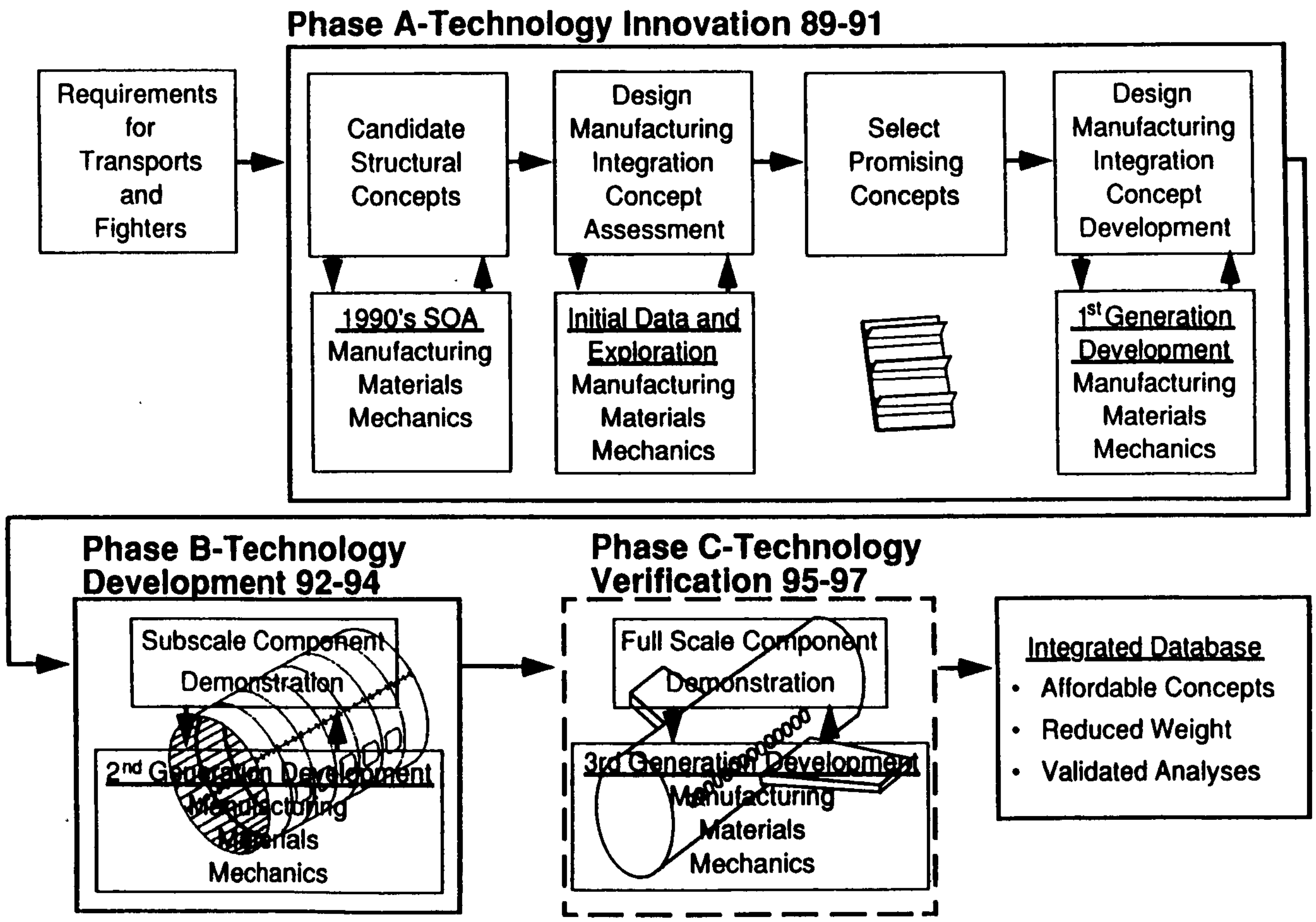
Gratitude is expressed to the Program Selection Committee for the Ninth DOD/NASA/FAA Conference on Fibrous Composites in Structural Design for allocating one day of the agenda for presentations on the ACT Program.

ACT PROGRAM LOGIC

The program plan began with definition of requirements for military and transport aircraft contains three phases, and ends with a verified integrated database. Phase A is complete and several candidate materials, concepts and fabrication methods that offer the potential for cost-effective composite structures were identified. Materials coupons, small panels and elements, and fabrication articles have been tested. Cost-effectiveness is the most challenging goal.

Focus of Phase B is a wing concept that exploits through-the-thickness stitching of dry fiber material and resin transfer molding and a fuselage concept that exploits a combination of automated fiber placement and textile preforms. A semi-span wing box for a 200 passenger aircraft will be developed and ground tested. Large panels representative of the crown, window belt and keel areas of Boeing-777 size aircraft will be developed and tested.

Phase C is not fully defined but the anticipated focus is large components at the wing body intersection and a full barrel with doors and windows aft of the wing.

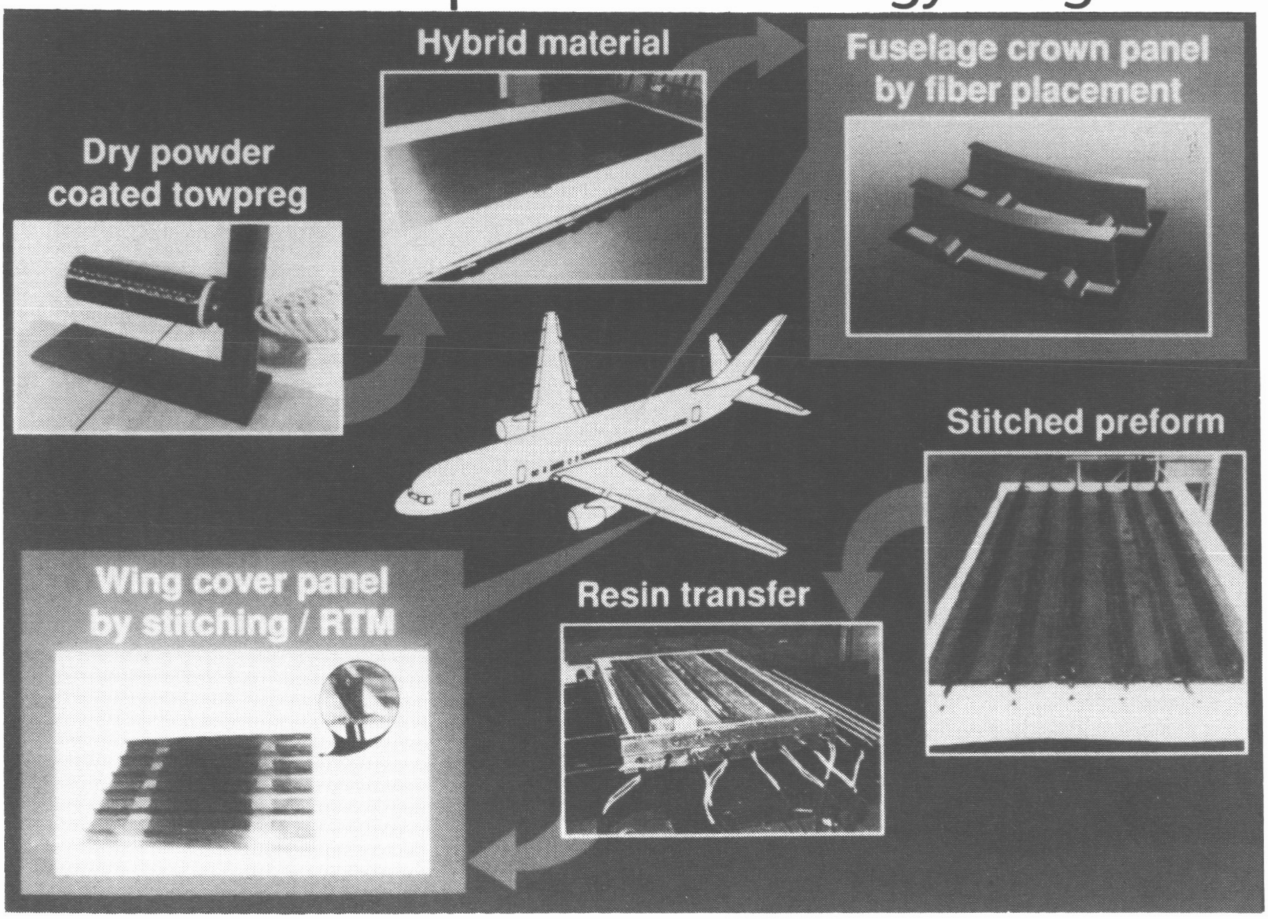


PHASE A SELECTED HIGHLIGHTS

Dry powder coated towpreg has been identified as a potential low cost method for producing material for use in weaving or fiber placement of structural components. Other advantages of the process are that solvents are not required and shelf life can be greatly extended. Use of intermediate strength and stiffness graphite/glass hybrids in tension-tension design applications such as the fuselage crown area appears to offer cost advantages compared to use of high modulus/high strength graphite. A crown panel design that is cost-effective relative to aluminum panels has been identified. Eliminating fasteners and reducing assembly cost are key features.

Wing panels up to six (6) feet in length have been fabricated and tested. Use of through-the-thickness preforms and resin transfer molding with state-of-the-art untoughened resins have produced panels which meet damage tolerance requirements. Test results indicate that delamination and stiffener separation are eliminated or greatly reduced compared to panels without through-the-thickness stitching. Resin transfer is through the thickness and thus major technical barriers to scale-up are not anticipated.

Advanced Composites Technology Program

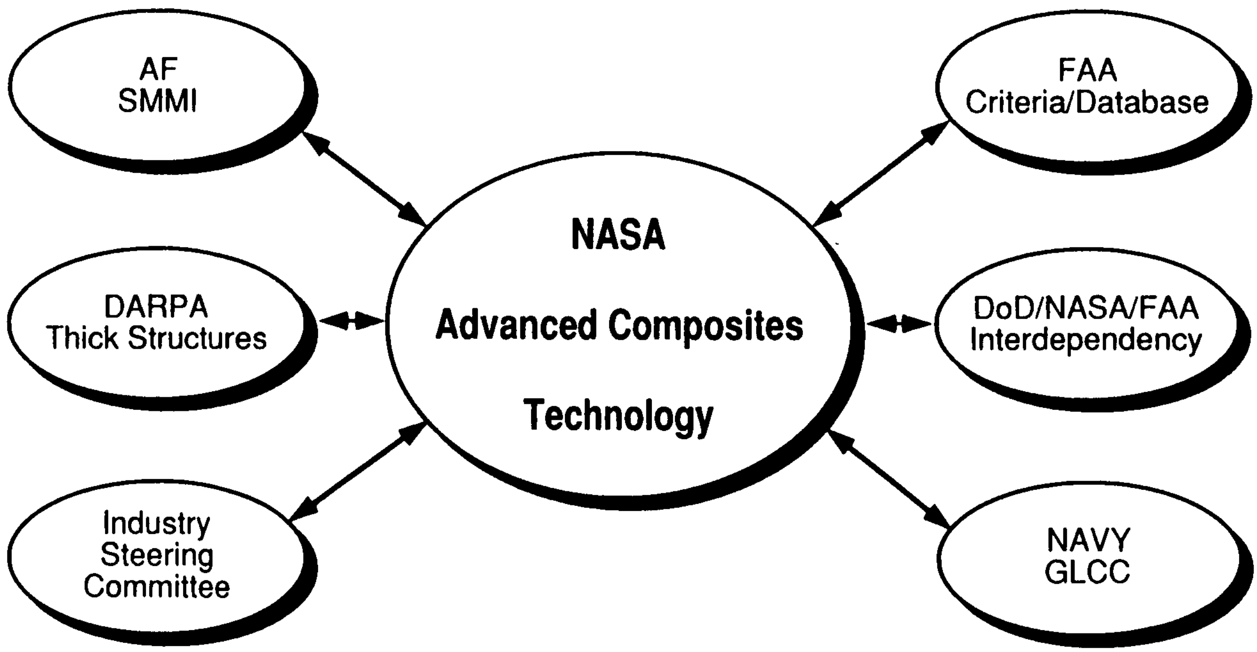


GOVERNMENT/INDUSTRY INTERFACE

NASA has established and maintained a strong interface with industry and other government agencies that are developing composite materials and structures technology for application to primary structures. This will insure that maximum synergism is obtained for each program, the maximum possible advancement in the state-of-the-art is achieved with the available budget, that lessons learned are shared between the participants, and the possibility of overlooking major technical obstacles is minimum.

It is anticipated that formal cooperative agreements will evolve from several of these interfaces. Joint conferences are already occurring and are planned for the future. Representatives from the various organizations have participated in several technical workshops. Common interest in developing cost models and common formats for collecting cost data have been identified.

Advanced Composites Technology Program



ACT STEERING COMMITTEE

The ACT Steering Committee was formed in 1990 and includes representatives from airframe manufacturers, a materials company, a commercial airline company, the U. S. Air Force, the Federal Aviation Administration and NASA Headquarters. Several members of the Langley Research Center staff serve an ex-offico role. These include the Director for Structures, Chiefs of the Materials and Structures Divisions and Manager of the Structures Technology Program Office.

The Committee has been charged to periodically critique the ACT Program and to provide recommended improvements. Technical, resource allocation and schedules are reviewed with the Committee. Three meetings have been held: November 1990, June 1991 and November 1991. The committee recommended that the focus of the ACT Program be narrowed to emphasize structural concepts that exploit stitched dry fiber/resin transfer molding, textile preforms and automated fiber placement. The recommendation has been implemented.

Members:	Jack McGuire	Boeing (Chairman)
	Dale Warren	Douglas
	Cecil Schneider	Lockheed
	Sam Dastin	Grumman
	Robin Whitehead	Northrop
	John DeVault	Hercules
	Terry Hertz	NASA
	Robert Neff	U.S. Air Force
	Joe Soderquist	FAA
	Jim Epperson	American Airlines
Ex-Officio Members:	Charles Blankenship	NASA
	Darrel Tenney	NASA
	John Malone	NASA
	John Davis	NASA

NASA/ACT FOCUSED RESEARCH TEAMS

Four primary research teams have been established. Three are in response to the ACT Steering Committee recommendation. Each of the specific technical thrust areas has a lead airframe contractor. The other organizations perform a supporting role.

Boeing is the lead contractor for the Automated Fiber Placement team and Hercules, Stanford, University of Utah(B), LaRC Materials Division and Structural Mechanics Division are supporting members.
Douglas is the lead contractor for the RTM/Stitched team and Dow, LaRC Materials and Structural Mechanics Divisions are supporting members. Lockheed is the lead contractor for the Textile Preforms team and Grumman, Rockwell, BASF, LaRC Materials, Structural Mechanics, and Structural Dynamics Divisions are Supporting members.

A portion of the research and development that was initiated early in the program is generic, and performing organizations are listed under Supporting Technology.

Automated Fiber Placement

- Boeing Commercial Airplanes
- Hercules
- Stanford University
- University of Utah (B)
- LaRC Materials Division
- LaRC Structural Mechanics Division

RTM/Stitched

- McDonnell Douglas
- Dow Chemical
- LaRC Materials Division
- LaRC Structural Mechanics Division

Textile Preforms

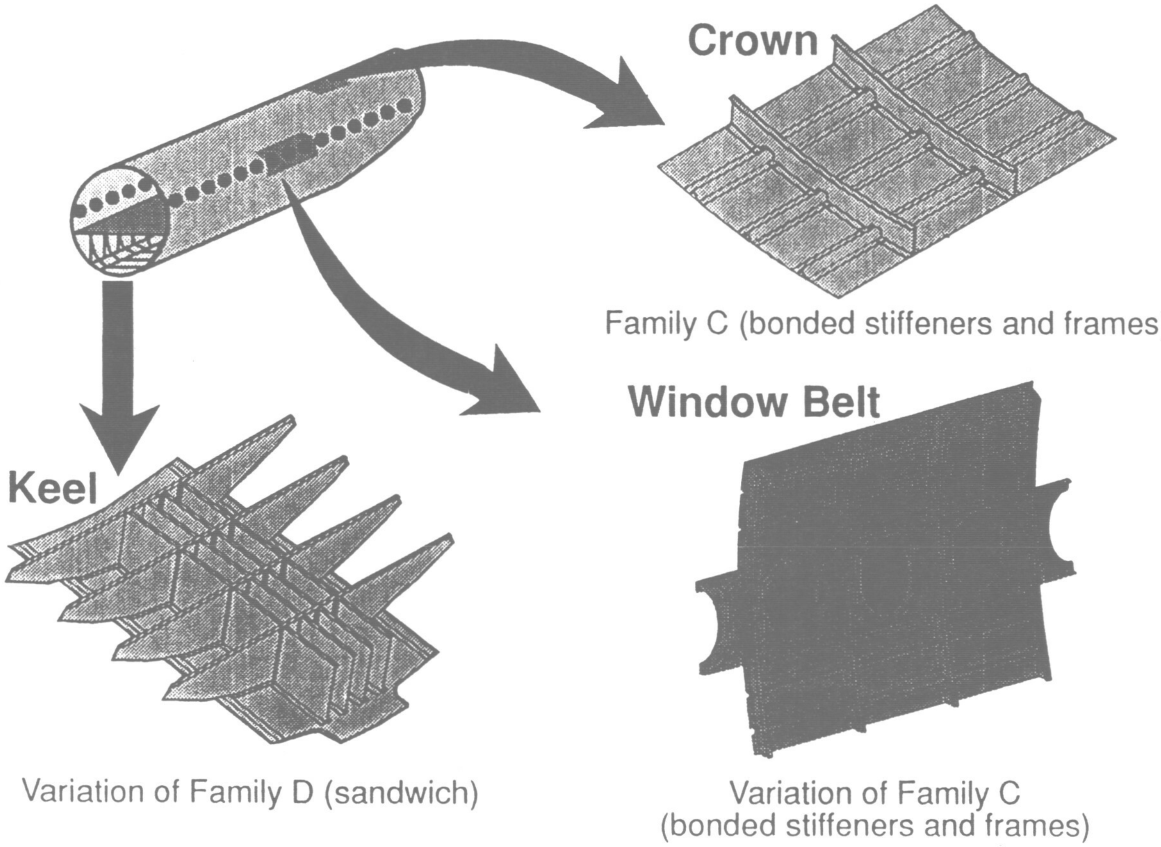
- Lockheed Aeronautical Systems
- Grumman
- Rockwell International
- BASF
- LaRC Materials Division
- LaRC Structural Mechanics Division
- LaRC Structural Dynamics Division

Supporting Technology

- University of Utah (N)
- Sikorsky
- University of Cal-Davis
- University of Delaware
- Northrop
- LaRC STPO
- LeRC Structures Division

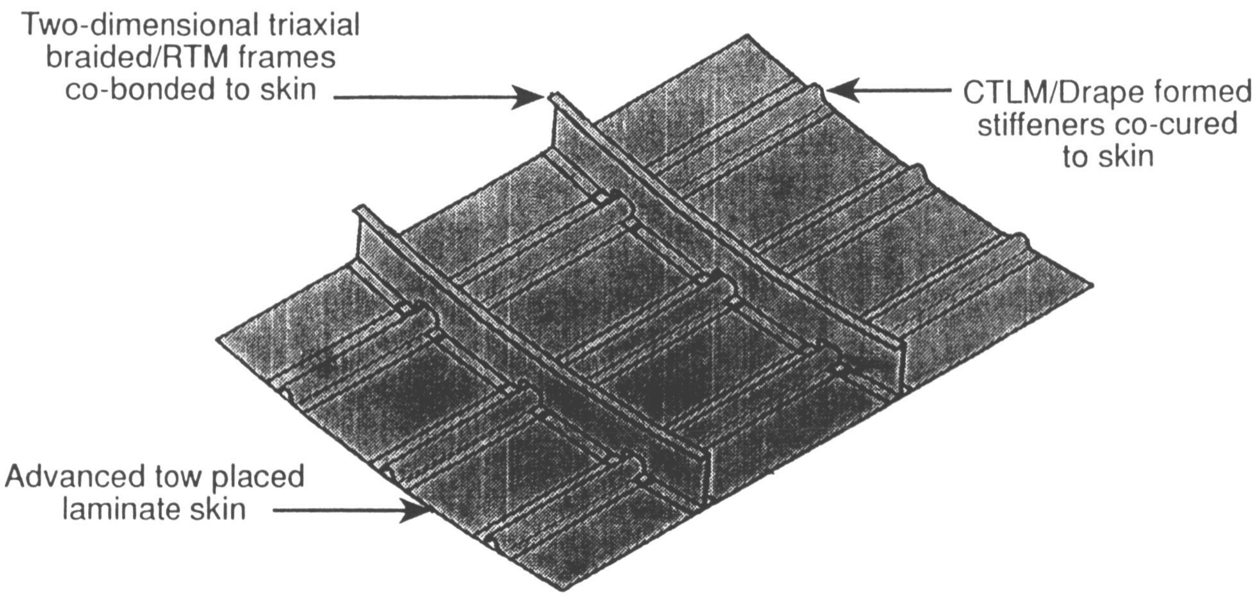
BASELINE FUSELAGE CONCEPTS

Boeing Design-To-Build-Team(DBT) studies early in Phase A of the ACT Program concluded that the most probable approach for achieving cost-effective fuselage structure is to build the barrel in quadrants. Variation in design load requirements in the crown, side and keel areas, fabrication and assembly considerations, inspection and repair requirements lead to this conclusion. The skins for all panels will be fabricated by continuous AFP. Three cylindrical mandrels will be used to AFP four crown, four side and ten keel panels. The skins will be cut, removed from the mandrel, and laid into a tool for subsequent cure and bonding of stringers and frames. The baseline frames are textile preforms that are impregnated by RTM.
The baseline window belt frames are also textile preforms/RTM and will be developed by Lockheed under contract to NASA.



BASELINE CROWN QUADRANT

The baseline design for the crown quadrant section of the fuselage contains a mixture of technologies that was selected on the basis of Design to Build Team(DBT) meetings that addressed cost, weight, maintenance, inspection and repair. AFP was selected for the skin. The hat-shaped stiffeners will be fabricated using the Contour Tape Layed Mold(CTLM)/Drape forming process. A two-dimensional triaxial braided textile preform that will be impregnated with the resin transfer molding process will be used to build frames. The frames will be co-bonded to the skin whereas the stiffeners will be co-cured with the skin. Current estimates indicate a fifty percent reduction in weight and approximately thirty percent reduction in cost compared to aluminum aircraft structure. A significant portion of the cost savings is attributed to the size of one composite panel (approximately twenty five percent of the fuselage circumference and 30 feet in length) compared to numerous aluminum panels required. Elimination of thousands of fasteners compared to the metal panels also contributes to the cost savings. Graphite/epoxy material remains as a major cost center.



Notes from Global Optimization

Comparison with aluminum 767-X
- 50% weight savings
- Potential for up to 30% cost savings in local optimization
- Major cost center: Material

TOTAL FUNDING BY FISCAL YEAR

Funding for each specific thrust area is shown. Taking into account the applicability of some of the textile preform research and development to the RTM/stitched thrust, the funding for each of the three specific thrust areas is approximately the same. Funding for the generic supporting technology is less and reflects the decision to narrow the program focus. The funding shown does not include ACT Program resources that have been redirected to support research and development of materials and structures for high speed civil transport type aircraft.

ACT Focused Research Program

	ϕA →	←	ϕB	→		
Research Areas	**Prior Years**	**FY91**	**FY92**	**FY93**	**FY94**	**Total**
Automated Fiber Placement	7441	8076	6179	4986	5897	**32579**
RTM/Stitched	5670	4284	5672	5292	5183	**26099**
Textile Preforms	3715	9158	9016	9900	9350	**41138**
Supporting Technology	6572	3360	3435	4505	4870	**22742**
Total	**23398**	**24877**	**24301**	**24682**	**25300**	**122558**

RESPONSIBILITY FOR NASA/ACT RESEARCH TEAM FOCUSING ON AUTOMATED FIBER PLACEMENT (AFP)

Boeing is responsible for overall design, analyses, fabrication and testing of transport fuselage concepts that exploit the AFP process. Hercules is responsible for the fabrication of panels that will be used to validate structural and cost performance. Stanford University is conducting tests and developing compression damage tolerance analysis methods. University of Utah is investigating failure mechanisms that affect tension damage tolerance. University of Delaware is developing technology to design and predict the response of Long Discontinuous Fiber(LDF) frame concepts. The Materials Division of the NASA Langley Research Center is investigating new material forms that offer potential for cost savings. The Structural Mechanics Division of the NASA Langley Research Center is conducting advanced analyses and performing tests to verify the performance of the AFP concepts and to insure that the technology basis is sufficiently mature to predict the response under load.

Boeing Commercial Airplane Group (ATCAS Program)

- Coordinate team efforts to concentrate on critical technical issues
- Lead DBT studies to optimize quadrant designs and manufacturing plans
- Formulate preliminary design cost model
- Create process and test plans for development and validation tasks
- Demonstrate composite fuselage manufacturing technology
- Develop analyses/perform tests to link material and structural performance
- Validate composite fuselage performance using analyses and tests
- Document technology databases (design, process, test, and analysis)

Hercules Incorporated

- Support DBT on design, process, and performance issues with emphasis on AFP
- Process manufacturing demos and test articles as specified by DBT decisions

Stanford University

- Damage tolerance analysis methods and "Impact" software
- Impact tests database

University of Utah

- Characterize failure mechanisms affecting the tension damage tolerance of AFP laminates
- Identify relationships between AFP process variables and critical failure mechanisms

University of Delaware

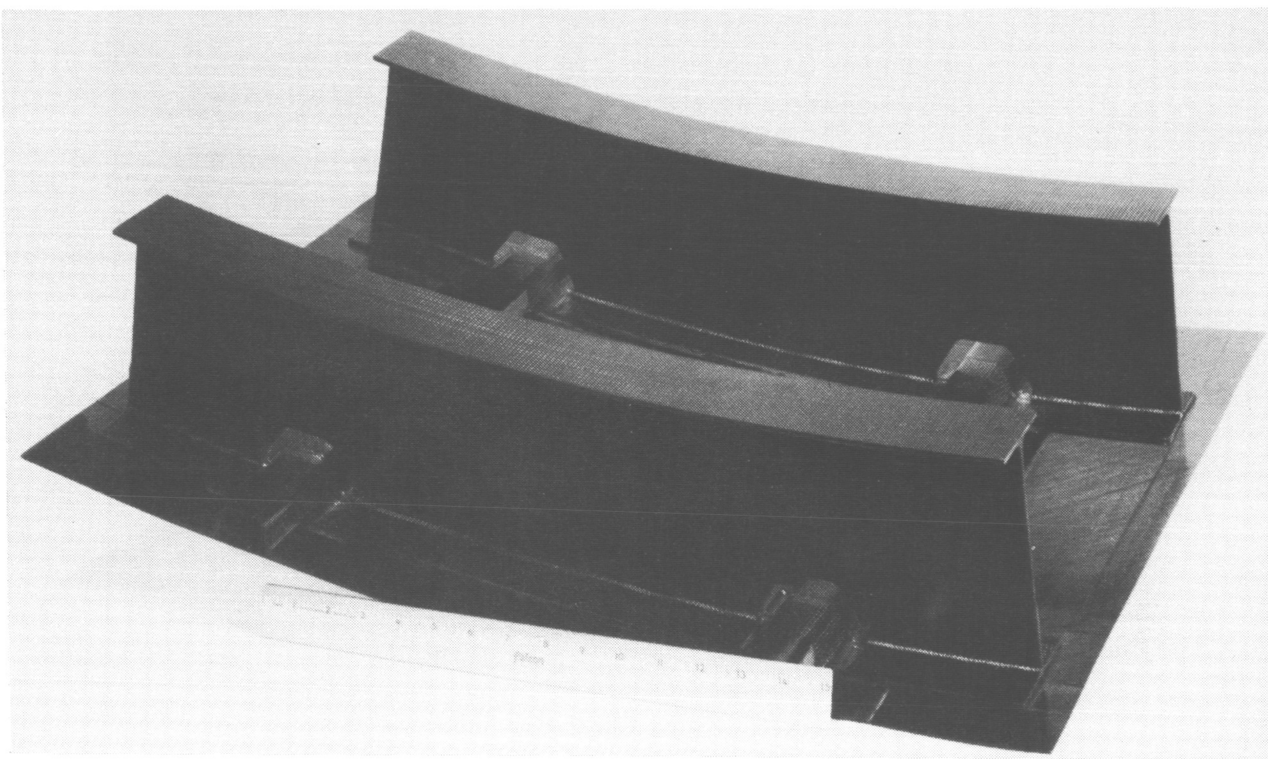
- Identify a BCA frame design for demonstrating LDF manufacturing approach
- Process, analyze, & test frames to validate LDF technology

NASA (MD, SMD)

- Conduct research on mechanics of advanced materials
- Conduct advanced studies on damage tolerance for transport fuselage

INITIAL TOOL PROOF ARTICLE FOR AFP CROWN PANEL

The first tool proof panel fabricated by Boeing is shown. A small curved panel with two "I" frames and two hat stringers was fabricated and cured with the a soft tooling concept. The radius of curvature for the panel is 74 inches. The panel was cured under 150 psi pressure on a steel outer mold line tool. The purpose of the tool proof article was to evaluate dimensional accuracy and bond quality for the fabrication approach. Additional trials are planned for 3 feet x 5 feet panels and the 7 feet x 10 feet crown verification panels. The soft tooling concept uses silicon rubber bag material that is selectively reinforced with graphite fiber to provide stiffness for dimensional stability at cure temperatures. The flexible caul concept provides a low cost way to accurately locate stringer cross sections and panel taper in the composite panel. Additional papers on this subject are included in the proceedings of this conference.



RESPONSIBILITY FOR NASA/ACT RESEARCH TEAM FOCUSING ON RESIN TRANSFER MOLDING(RTM) TECHNOLOGY

Douglas is responsible for overall design, analyses, fabrication and testing of transport wing and fuselage concepts that exploit the stitched dry fiber/RTM process. William and Mary College and Virginia Polytechnic Institute and State University are developing flow and cure models and performing related experiments. Ketema and Pathe are developing automated high speed sewing machines to stitch the cover panels and to attach stiffeners to the cover panels. The Materials Division of the NASA Langley Research Center is conducting tests on specimens and small panels to assess mechanical properties and environmental effects. The Structural Mechanics Division of the NASA Langley Research Center is conducting advanced analyses and performing tests to verify the performance of the stitched dry fiber/RTM concepts and to insure that the technology basis is sufficiently mature to predict the response under load. Hercules will build an AFP fuselage panel that will provide a direct comparison with a RTM panel.

Douglas Aircraft Company

- Develop through-the-thickness stitching concepts for damage tolerant structures
- Create processes and tooling for RTM of stitched preforms
- Develop analyses/perform tests to link material and structural performance
- Demonstrate composite wing and fuselage manufacturing technology
- Validate composite structures performance using tests and analyses
- Document technology databases (Design, Process, Test and Cost)

Hercules Incorporated

- Support Douglas on ATP process and tooling issues
- Fabricate tooling for ATP fuselage panels designed by Douglas
- Build panel test articles for process demonstration

Ketema, Inc. and Pathe

- Stitch dry carbon fabric preforms for concept developments
- Develop high speed stitching machines for structural preforms
- Demonstrate new machines on panel preforms

William and Mary College

- Measure cure kinetics of RTM resins
- Devise manufacturing thermal cycles
- Develop instrumentation for monitoring RTM processes

V.P.I. and State Univ.

- Develop RTM flow and cure models
- Characterize flow properties for stitched preforms
- Devise optimum heat and pressure cycles

NASA (MD, SMD)

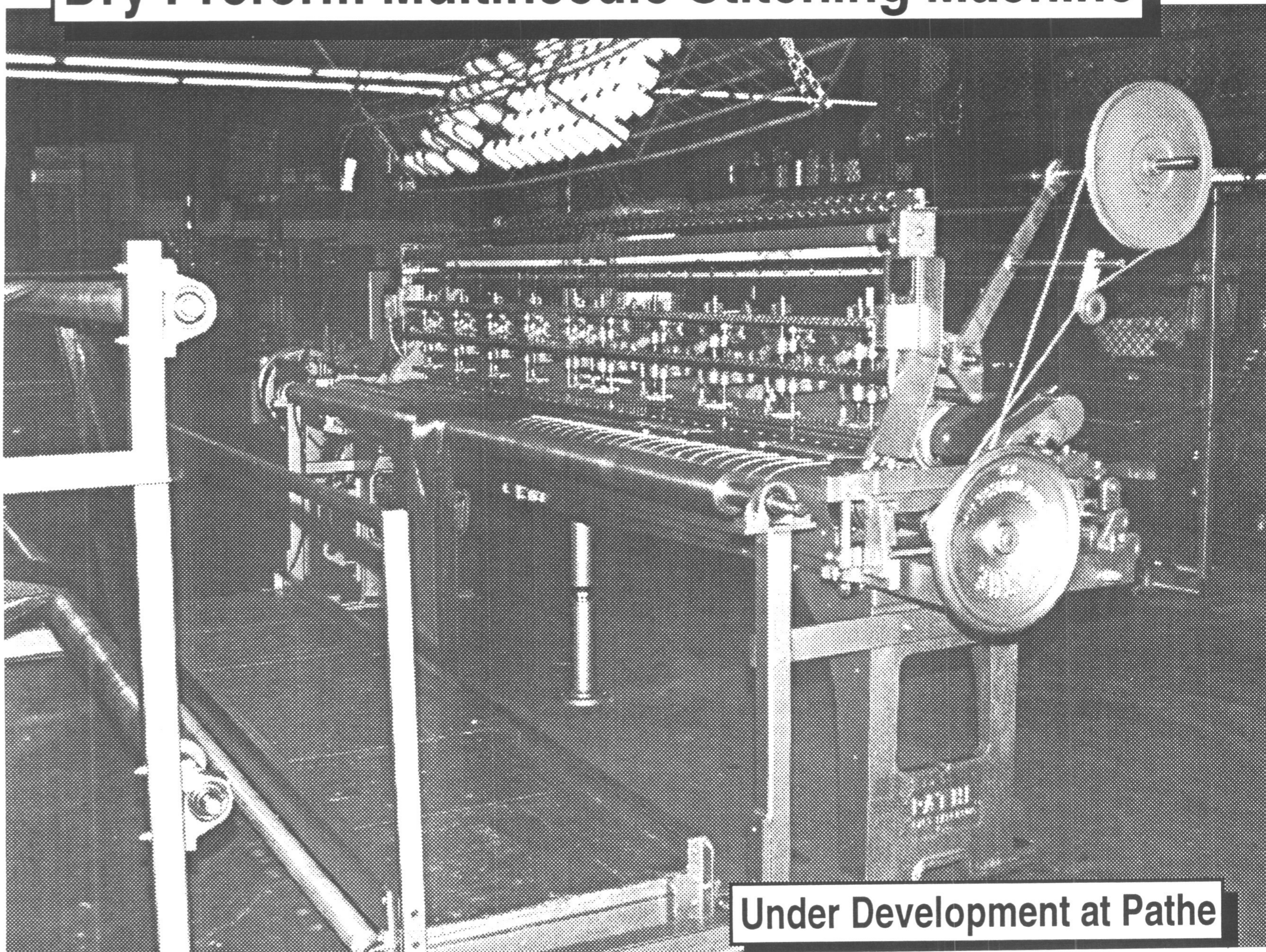
- Test stitched/RTM laminates for properties and CAI strength
- Perform studies on mechanics of stitched composite materials
- Test ATP and RTM fuselage panels

DRY PREFORM MULTINEEDLE STITCHING MACHINE

The multineedle machine, with up to 256 needles, is mechanically controlled and can accommodate up to a 128 inch wide preform. Material up to one-half inch thick or 72-ply nominal 0.006 inch per ply preforms can be sewn. The machine will perform a wide range of stitching densities (light-1 inch on center with 100 denier thread to heavy-3/16 inch on center with 1500 denier thread). Capability is limited to lock stitching. Speed varies according to stitch density but the machine is expected to be capable of stitching a wing cover panel 8 feet by 12 feet in size in one hour. The machine is scheduled to be fully operational in the first quarter of calender year 1992.

(See photograph on following page)

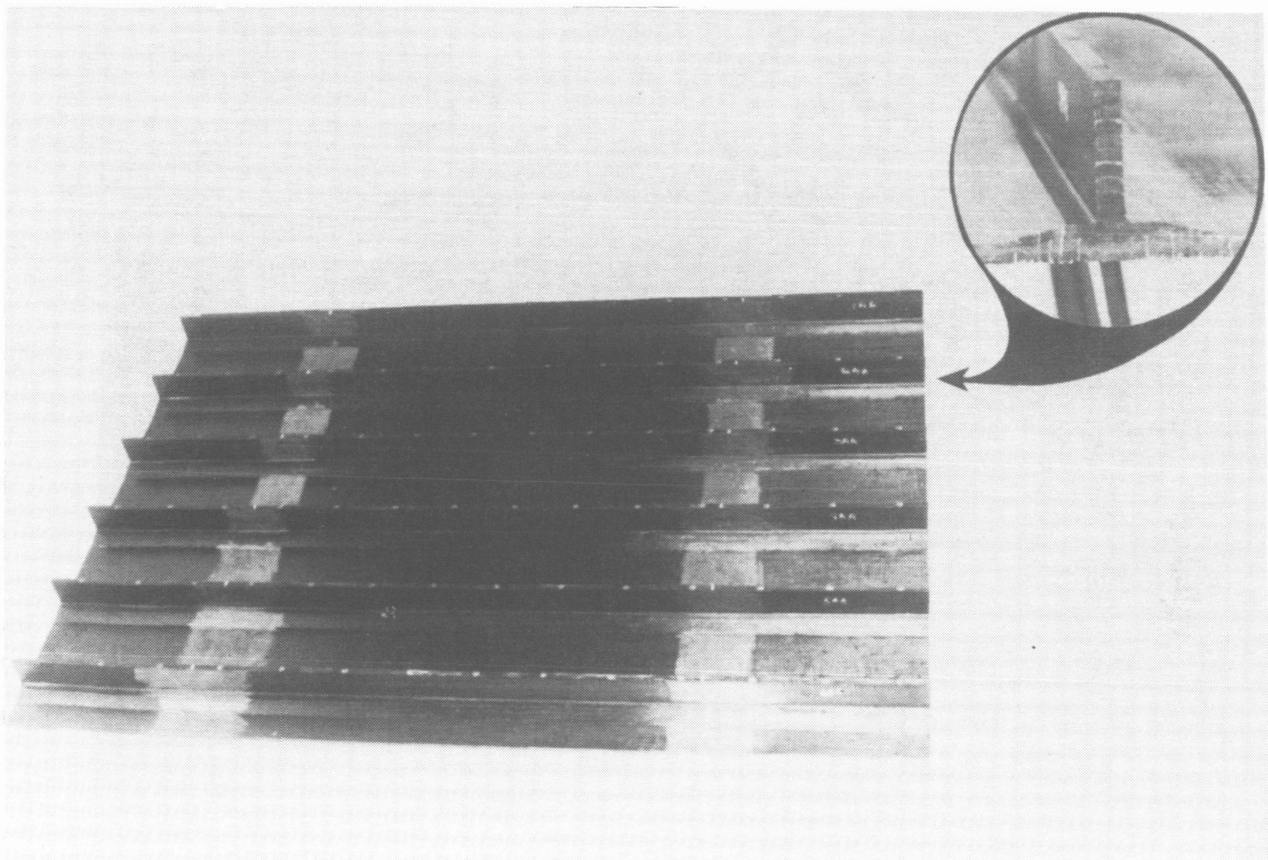
Dry Preform Multineedle Stitching Machine



Under Development at Pathe

DAC STITCHED/RTM WING PANEL

A six foot by four foot six stringer wing panel is shown. The cover panel was fabricated as follows: a dry preform was stitched throughout the planform area, stiffeners were next attached to the planform by stitching, and the dry preforms were subsequently placed in a mold, compacted, impregnated by resin film infusion and cured formed. Fabrication of this panel represents a significant step in the scaleup of the RTM process for skin stiffened structural components. Through-the-thickness stitches which provide enhanced damage tolerance and resistance to skin stiffener separation are visible in the enlarged section of the photograph. Mechanical tests are being conducted on these types of panels to verify the load carrying capacity and the analyses capability to predict structural response. Future research and development will include building and ground testing a semispan wing box for a 200 passenger size transport aircraft to verify weight savings, cost savings and integrated technology base.



RESPONSIBILITY FOR NASA/ACT RESEARCH TEAM FOCUSING ON TEXTILE PREFORM TECHNOLOGY

Lockheed is responsible for overall design, analyses, fabrication and testing of fuselage components that exploit textile preform technology. Lockheed and Boeing are working together in DBT's to select a window belt design that Lockheed will develop. The window belt will subsequently be incorporated into a side panel that Boeing will test. Rockwell is conducting a basic investigation on the fatigue response of woven materials. BASF is developing powder coated tow that will be woven into textile preforms. Grumman is focusing on cross-stiffened elements and an integrally woven fuselage panel. The Materials and Structural Mechanics Divisions of the NASA Langley Research Center are conducting fundamental studies on mechanics of materials and will perform tests to verify capability to predict structural response.

Lockheed Program

- Develop advanced resin systems
- Demonstrate preform fabrication and processing methods
- Develop low cost preform fabrication techniques and equipment
- Design and fabricate crown and lower side quadrant fuselage components
- Document databases for design, process and analysis
- Validate structural response and failure analysis methods

Rockwell

- Fatigue characterization of woven materials

BASF

- Powder coated tow-preg material development

Grumman Aircraft

- Support DBT to design, fabricate and test a cross-stiffened integrally woven element
- Fabricate and deliver to LaRC for test, an integrally woven fuselage panel

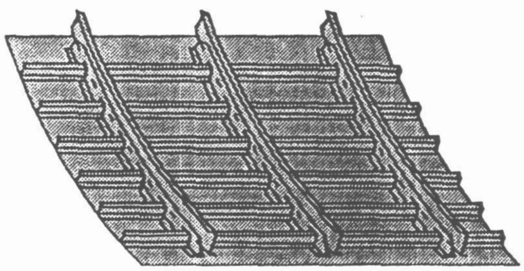
NASA (AMB, PMB, MeMB, ASB)

- Lead studies on mechanics for advanced textile architecture
- Develop RTM inplane flow models
- Conduct benchmark panel tests
- Demonstrate weaving of powdered tow-preg
- Develop analytical methods, modeling and test standardization
- Develop micromechanics for fatigue and test standards

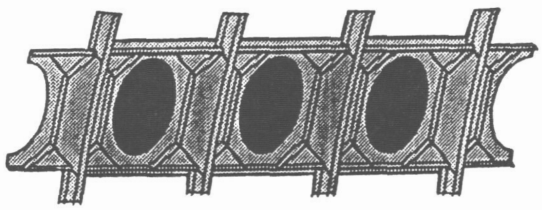
TEXTILE REINFORCED COMPOSITE STRUCTURAL C0MPONENTS

Four basic types of fuselage structural components have been selected to focus the technology development for textile preforms: integrally woven stiffened panels, circumferential frames, window belt insert and keel beam frame intercostals. These components must support out of plane loads and can benefit from the improved damage tolerance potential of textile preforms. All material, fabrication methods and analytical development will be directed at achieving lower cost and lower weight components compared to metallic structure. Full scale panels, approximately 6 feet in length and with a circumferential arc length sufficient to include five stiffeners will be built and tested to verify the cost and weight savings compared to metal components. The circumferential frames will have a radius equal to that of a large transport aircraft and be at least 8 feet in arc length.

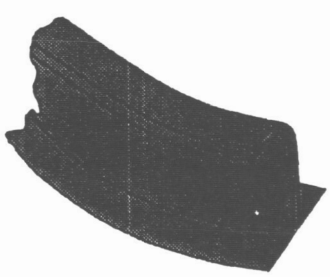
Benchmark/Crown Lower/Side Panels



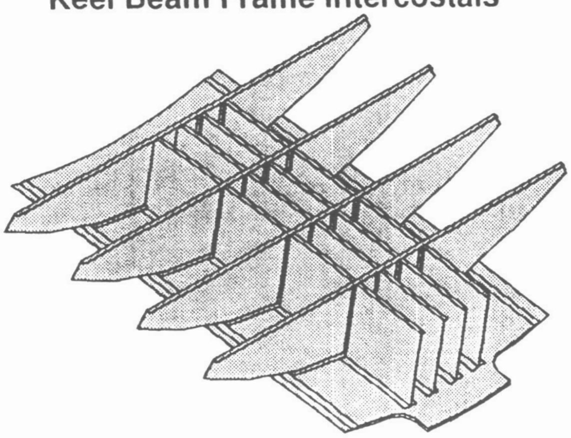
Window Belt Insert



Circumferential Fuselage Frames

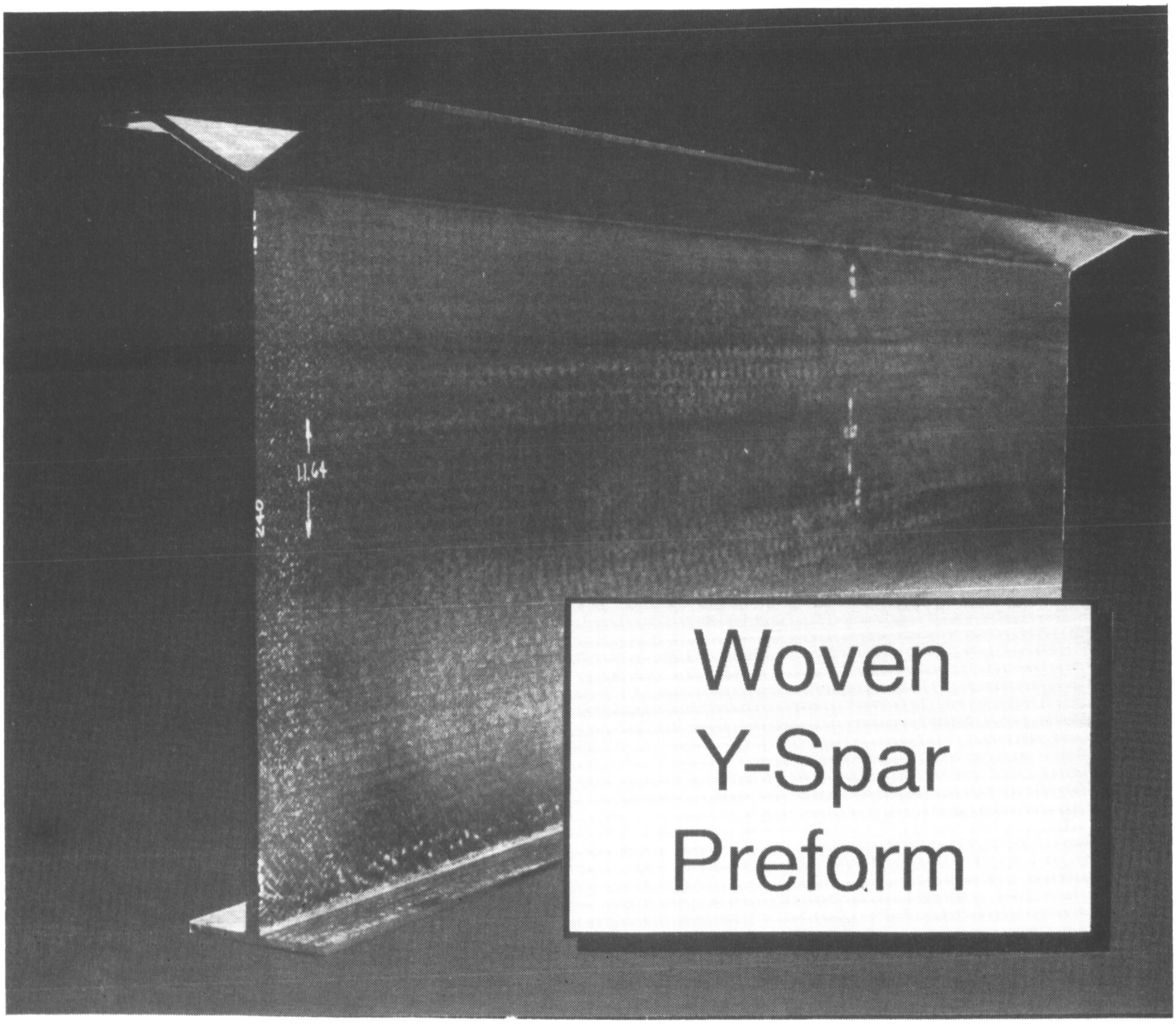


Keel Beam Frame Intercostals



WOVEN Y-SPAR PREFORM

The 40 inch long Y-spar shown in the photograph was fabricated by Textile Technologies on a Jackuard loom using angle-interlock fiber architecture. AS4 is the graphite reinforcing fiber and PEEK 150-g tows formed the matrix for the angle interlock layers. 0/90-degree weave and ±45-degree fabric layers were stitched to the interlock layer with fiberglass threads. The commingled preform was consolidated at 720°F and 160 psi. Percent fiber volume percent, resin volume, and void content were 56.1, 42.8 and 1.1, respectively. The spar was subsequently tested in four point bending and failed when the tensile stress in the upper cap exceeded the open-hole tensile strength. Details can be found in the paper by Suarez and Dastin.



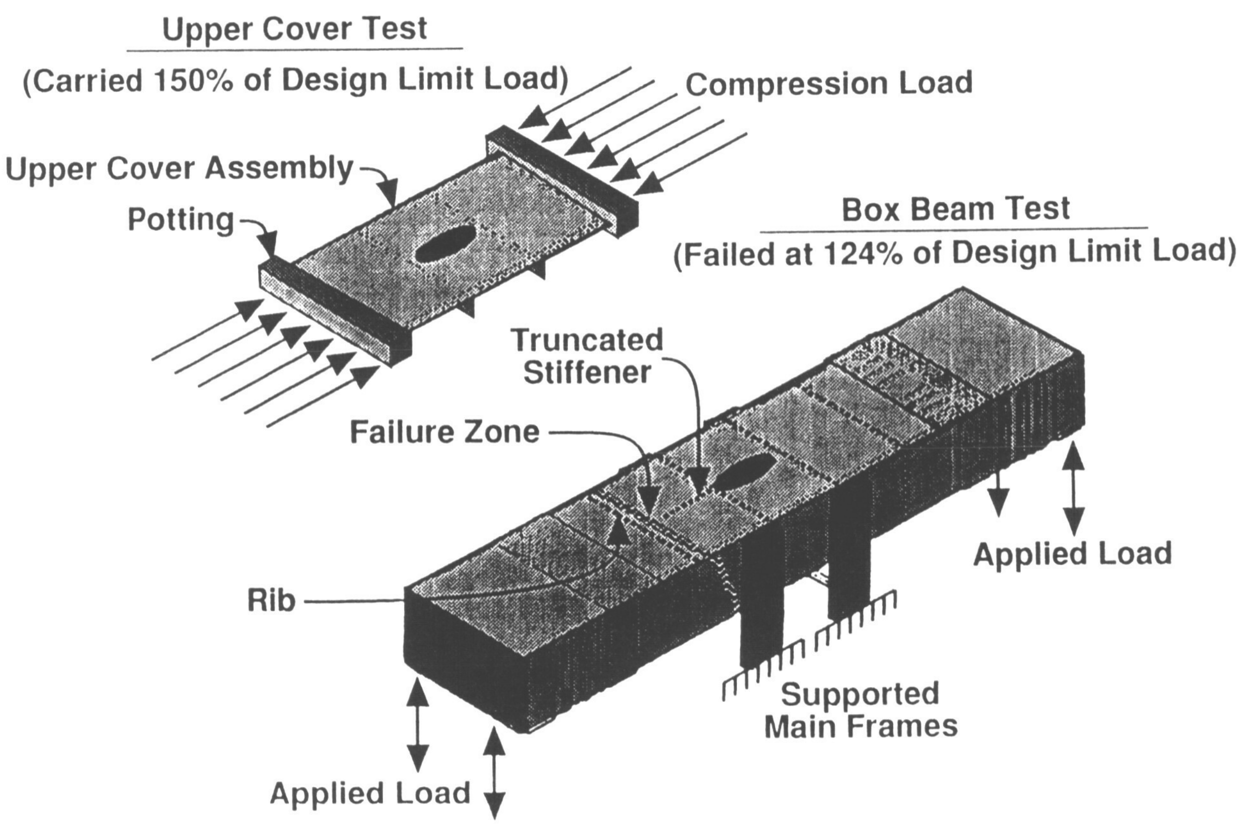
ACT FOCUSED PROGRAM
SUPPORTING TECHNOLOGY

In addition to the specific focused technology development that is underway for the three areas described herein before, there are a number of tasks underway that are applicable to a wider range of technical approaches or concepts. These items include laminate failure analyses by University of Utah, development of the Therm-X tooling process by Sikorsky, use of composite structures to achieve aeroelastic tailoring of wing box structure by University of California at Davis, analyses and tests of Long Discontinuous Fiber(LDF) beams by University of Delaware, testing of an integrated technology wing box structure by Lockheed, development and application of structural mechanics methodology by NASA organizations and development of cost models and cost database for composite structures.

Performing Organization	Deliverables
Utah (N)	Laminate Failure Analyses
Sikorsky	4' x 6' Therm-X Window-Belt Panel
Cal-Davis	Aeroelastic Tailoring Methodology
Delaware	LDF Frame Demo
Lockheed	Box Beam Tests
LeRC Probabilistic Mechanics	Probabilistic Mechanics
LaRC Impact Dynamics Branch	Crash Dynamics Tests
LaRC Applied Materials Branch	Micromechanics Analyses Tools
LaRC Aircraft Structures Branch	Cylinder Response Under Combined Loads
LaRC Computational Structures Branch	Performance Analysis Test Bed Demo
LaRC Structures Technology Program Office	Cost Model Tracking/Demo

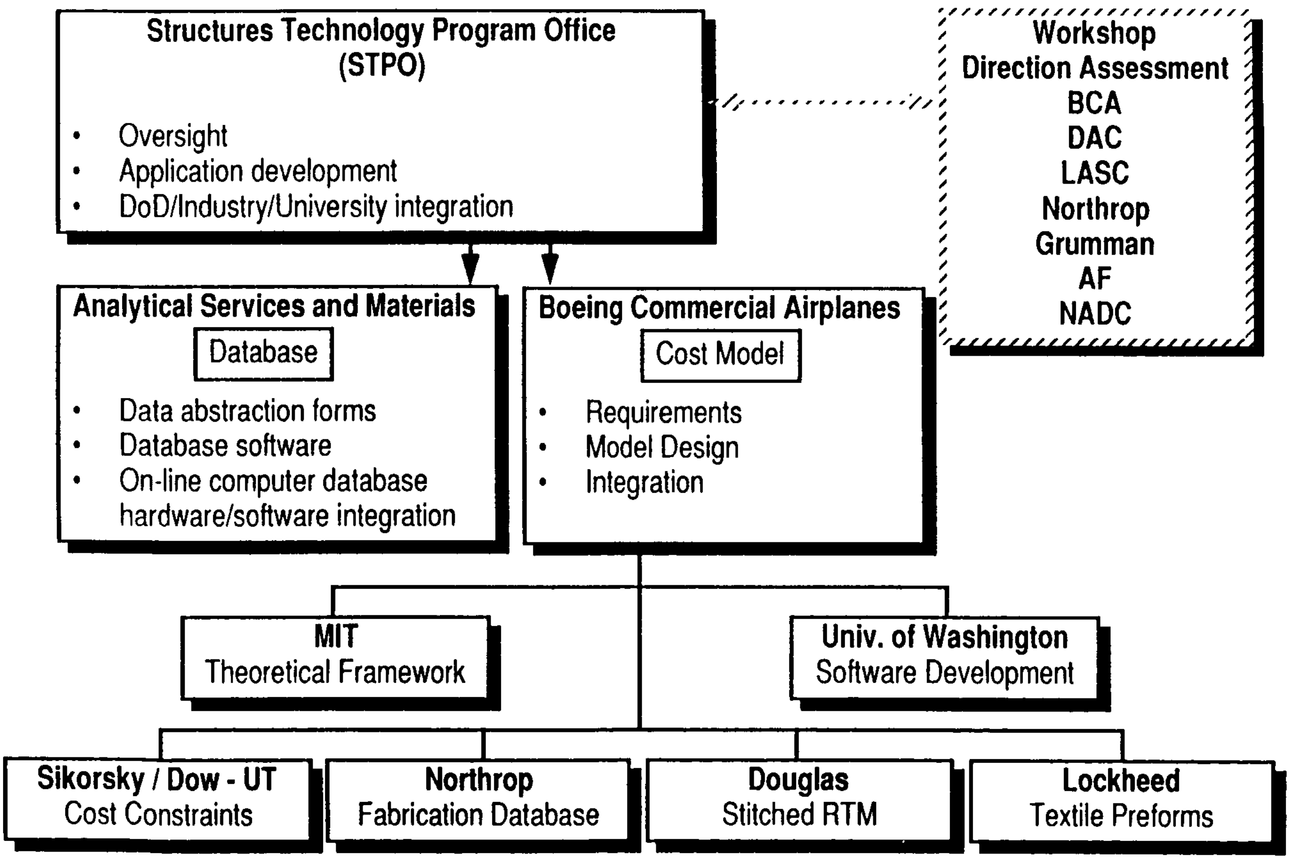
TECHNOLOGY INTEGRATED BOX BEAM TEST DEMONSTRATES IMPORTANCE OF LOAD INTERACTION

A comprehensive experimental and analytical investigation is under way to quantify the mechanisms that led to the failure of the Technology Integration Box Beam(TIBB) at a load level less than 150% of design ultimate load. Overall dimensions of the composite test section of the box are 150 inches long, 50 inches wide and 28 inches deep. Development tests prior to final fabrication of the box included an upper cover panel which supported design ultimate load. The panel was potted at the ends and this tended to restrain rotation at the ends. Experimental results from the box test indicate significant bending deformation of the hat stiffener and upper cover in the box. Preliminary analyses and study of the experimental results suggest that failure initiated in the upper cover skin due to severe bending in the region of the hat stiffener termination. A stiffener run out specimen is being defined and will be machined from the side of the box that did not fail. The specimen will be used to simulate the TIBB response and failure mechanisms. Further details are provided in the paper by Shuart,et.al..



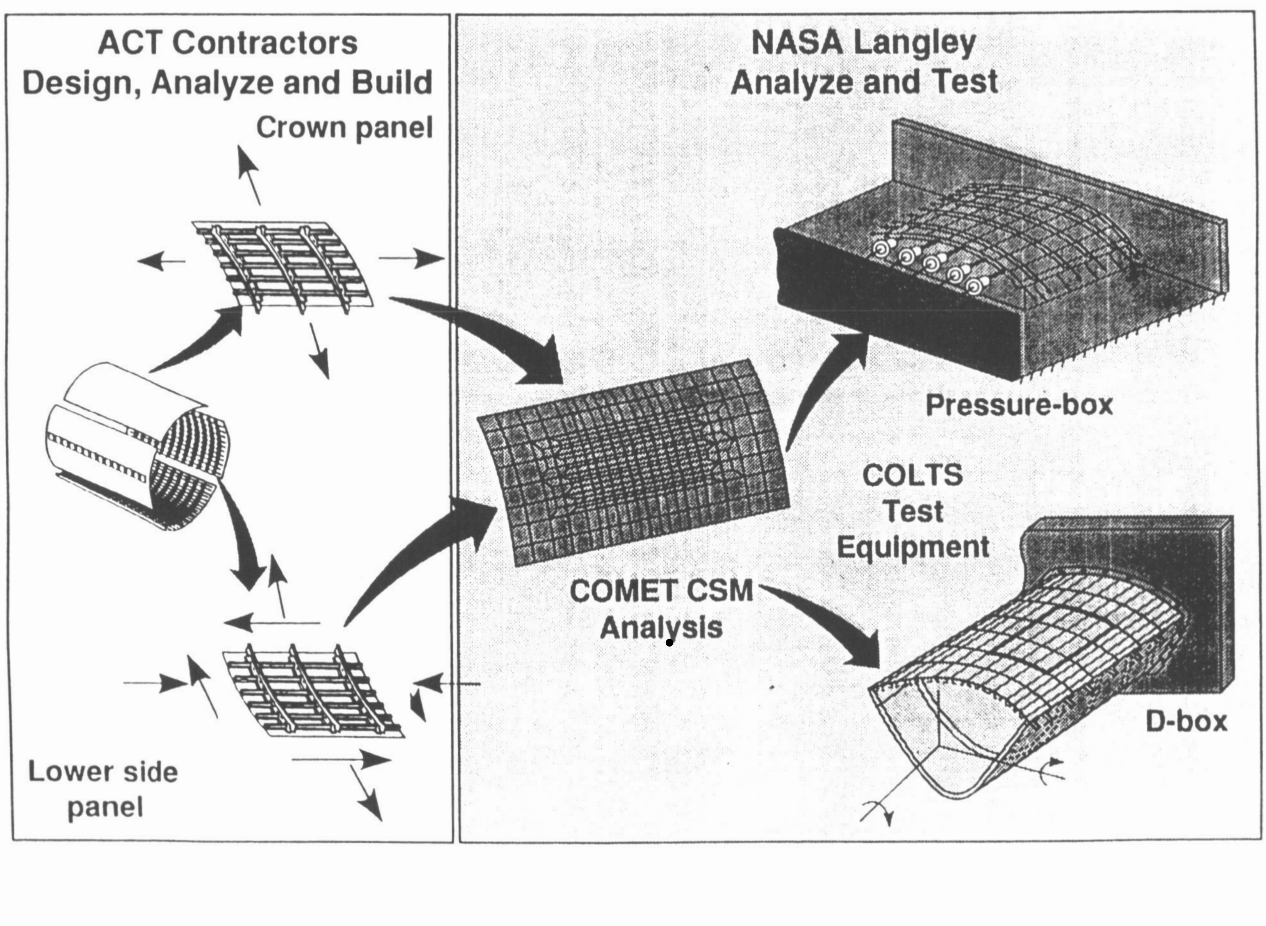
COST DATABASE AND MODEL DEVELOPMENT

A collaborative effort involving industry, university and government is being used to develop a database and cost model that conceptual and preliminary airframe designers can utilize to predict the relative cost of composite and metallic structures. The database has been designed to include important details that influence cost and can be accessed by personal computer. The cost model will be based on a theoretical framework that estimates cost as a function of the geometric features and the processes required to produce the design concept under study. Relationships developed will allow evaluation of the effect of design variables on the cost for individual components and the fully assembled structure. Additional details are found in the papers by Freeman, Ilcewicz and Swanson and Siddiqi, Vosteen, Edlow, and Kwa.



TECHNOLOGY BENCHMARK PLAN INTEGRATES INDUSTRY AND NASA ROLES

The technology benchmark components will be used to assess progress in materials, structural mechanics and manufacturing technologies. ACT Program contractors are designing fuselage crown, window belt and lower side panels. A set of common design criteria, loads and overall geometry has been defined. Boeing and Douglas are scheduled to build crown panels. Lockheed and Boeing are collaborating to build a window belt panel that is not depicted in the sketch. Grumman will also build a window belt panel. Boeing, Douglas and Grumman are scheduled to build lower side panels. Each design will utilize different combinations of materials, structural concepts and fabrication methods. NASA researchers will perform in-depth analyses and will test the panels. The first of nine planned Boeing crown panels is scheduled to be tested in the pressure-box in 1992. Subsequent tests will include different types of damage and some panels will be damaged and repaired prior to testing. Cost data on fabrication of the nine panels will be used to verify portions of the cost model under development in the ACT Program. Design of the remaining test fixtures has begun. All panels will be extensively instrumented to aide in determining load interaction between skin, stiffeners and frames and failure modes. Both pretest and post test analyses will be conducted to assess the capability to predict failure modes and response of the panels under simulated flight scenarios.



SUMMARY

Phase A of the ACT Program is nearly complete. The program has been focused to fully exploit structural concepts and materials combinations that may be fabricated by Advanced Fiber Placement, from Dry Fiber Stitched/RTM and /or Textile Preforms. Results obtained to date indicate that these fabrication methods used singly or jointly offer the best potential for achieving cost-effective primary structures. Experience thus far has indicated that concurrent engineering which integrates design and manufacturing in the beginning of the development cycle is essential to achieving the required cost-effectiveness. A collaborative effort with industry, university and government laboratory personnel has been initiated to develop methodology for predicting costs for fabrication and assembly of composite primary structures. A format for collecting the data has been established. Phase B of the ACT program will scale-up the materials, mechanics, fabrication methods and concepts defined in Phase A. The current plan is to design, fabricate and ground test a semispan wing box for a 200 passenger size aircraft and large fuselage panels for a Boeing 777 size aircraft.

- Phase A Technology Innovation is Nearing Completion
- Three Major Areas of Focus Have Been Selected:
  - Advanced Fiber Placement
  - Dry Fiber Stitched/RTM
  - Textile Preforms
- Cost Effectiveness of Design/Manufacturing Integration Has Been Demonstrated
- Methodology for Predicting Cost and Collecting Cost Data is Under Development
- Phase B Technology Development Has Been Initiated